

## Mystery of the Ly $\alpha$ Blobs

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**Abstract.** We present *Spitzer* Space Telescope observations of the extended Lyman  $\alpha$  blobs associated with the  $z=2.38$  over-density J2143-4423, the largest known structure (110 Mpc) above  $z=2$ . We detect all 4 of the Ly $\alpha$  blobs in all four IRAC channels and we also detect 3 out of 4 of the blobs with MIPS  $24\mu\text{m}$ . Conversion from rest-wavelength  $7\mu\text{m}$  to total far-infrared luminosity using locally derived correlations suggests all the detected sources are in the class of ULIRGs or even Hyper-LIRGs. We find a weak correlation between Ly $\alpha$  and mid-infrared emission for the Ly $\alpha$  blobs ( $L_{\text{Ly}\alpha}/L_{\text{bol}} = 0.05\text{--}0.2\%$ ). Nearly all Ly $\alpha$  blobs show some evidence for interaction, either in *HST* imaging, or the proximity of multiple MIPS sources within the Ly $\alpha$  cloud. This suggests that interaction or even mergers may be related to the production of Ly $\alpha$  blobs. Optical through infrared SEDs of the Ly $\alpha$  blobs do not show a clear  $1.6\mu\text{m}$  bump, but rather are indicative of a composite of star formation and AGN energy sources.

## 1. Introduction

The Ly $\alpha$  blob is a relatively new class of objects found among high-redshift galaxy over-densities ref (2007). While similar in extent ( $\sim 100$  kpc) and Ly $\alpha$  flux ( $\sim 10^{44}$  ergs s $^{-1}$ ) to high-redshift radio galaxies, blobs are radio quiet and are therefore unlikely to arise from interaction with jets. Current surveys have reported the discovery of roughly 10 of these giant Ly $\alpha$  blobs, but they are not isolated high redshift oddities. Matsuda et al. (2004; ref 2007) have demonstrated that the blobs are part of a continuous distribution of resolved ( $>16$  arcsec $^2$ ) Ly $\alpha$  emitters, with more than 40 presently known.

One of the standing mysteries of the blob is the source of their energy, as there is not enough rest-wavelength ultraviolet light visible along the line of sight from the host galaxies to excite such a vast quantity of hydrogen gas. One possibility is that the Ly $\alpha$  blobs are powered by supernova-driven superwinds ref (2007), driving great plumes of gas into the surrounding ambient medium and producing shocks. An obscured AGN is another model, with the exciting ultraviolet illumination escaping along different lines of sight ref (2007). Cooling flows have also been suggested ref (2007) as a possible Ly $\alpha$  power source.

## 2. Observations

We focus on the four known Ly $\alpha$  blobs found within the J2143-4423 over-density located at  $z = 2.38$  ref (2007). This high-redshift elongated string of galaxies extends over 110 Mpc, making it the largest known structure above  $z = 2$ , comparable in size to some of the largest structures seen in the local Universe (i.e. the Great Wall ref (2007)). Initially identified from narrow-band imaging tuned to Ly $\alpha$ , it has since been spectroscopically confirmed ref (2007,?).

Our data were obtained using the Multiband Imaging Photometer for Spitzer (MIPS; ref 2007) in 24  $\mu\text{m}$  photometry mode during October and November of 2004 and the Infrared Array Camera (IRAC; ref 2007) in May of 2005. The observation mapped the central area of the filament structure, covering an area approximately  $15 \times 25$  arcminutes. The final integration time per pixel for both MIPS and IRAC was  $\sim 1800$  seconds, reaching  $5\sigma$  limits of roughly 1, 1, 10, 15, and 80  $\mu\text{Jy}$  for 3.6, 4.5, 5.8, 8.0, and 24  $\mu\text{m}$  respectively.

## 3. Infrared Detections of Ly $\alpha$ Blobs

There is growing evidence that Lyman  $\alpha$  blobs mark regions of extreme infrared luminosity. Submillimeter flux has been detected in two of the larger known Ly $\alpha$  blobs, SMM J221726+0013 ref (2007) and SMM J17142+5016 ref (2007). More recently, Geach et al. (2005; ref 2007) has detected submm flux from four of the smaller ( $< 55$  square arcsec) and less luminous ( $< 2 \times 10^{43} L_{\odot}$ ) Ly $\alpha$  blobs from Matsuda et al. (2004; ref 2007): LAB5, LAB10, LAB14 & LAB18. Also, Dey et al. (2005; ref 2007) has discovered a single Ly $\alpha$  blob (SST24 J1434110+331733) in the NOAO Deep Wide-Field Survey with strong 24  $\mu\text{m}$  flux (0.86 mJy).

We continue to find evidence of strong infrared activity in these sources, detecting three of the four filament Ly $\alpha$  blobs with MIPS 24  $\mu\text{m}$ . For two of the blobs, the coordinates for the centers of the MIPS and Ly $\alpha$  sources agree to less than an arcsecond, while Blob B7 has a separation of 2.5'' between Ly $\alpha$  and MIPS centroids. This separation is significantly less than the MIPS FWHM: 5.9'' and well within the large area covered by extended Ly $\alpha$  emission. Accounting for source brightness the probability of chance superposition is below 0.3% for all sources.

Two of the Ly $\alpha$  blobs, B6 and B7, appear to have additional MIPS sources associated with them. The B6 Ly $\alpha$  blob extends over 25'', or over 200 kpc at  $z=2.38$ , and contains more than one knot or concentration (see Figure 1). The brightest Lyman  $\alpha$  knot is the central one and it is associated with a bright MIPS source, but the southern knot (not to be confused with the large diffuse area to the southeast) also has a MIPS source of almost identical brightness. There is also an area of more diffuse Lyman  $\alpha$  emission to the north which also appears to be associated with a bright MIPS source. Each source is separated by approximately 9.3'' from the central source, creating a potential triple system. However, examination of the optical through IRAC colors of the northern source reveal that it must lie at a lower redshift.

The center of the B7 Ly $\alpha$  blob actually lies between two sources. We have associated it with the brighter, closer MIPS source 2.5'' to its southeast, but a second source lies 5.5'' to the northwest. While there is a  $\sim 10\%$  chance

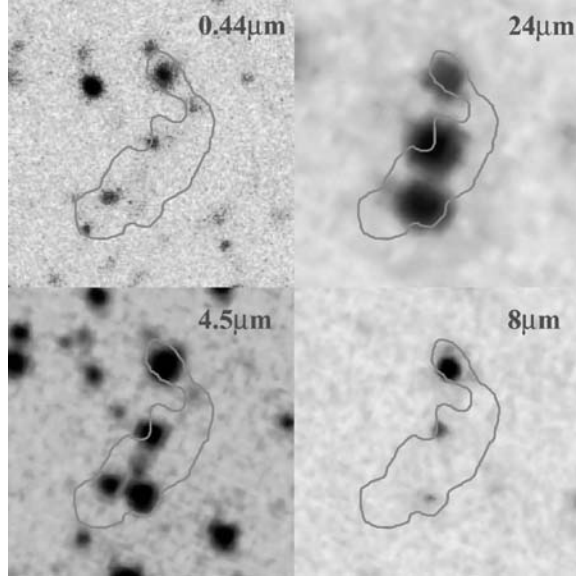


Figure 1. Images of the  $40'' \times 40''$  field around the MIPS-detected  $\text{Ly}\alpha$  blob B6. Starting top left and moving clockwise the images are CTIO B-band, MIPS  $24\mu\text{m}$ , IRAC  $8.0\mu\text{m}$ , and IRAC  $4.5\mu\text{m}$ . Overlaid over all four images is the outer contour of  $\text{Ly}\alpha$ -emission. One arcsecond corresponds to 8kpc at  $z=2.38$ .

the second object could be chance association, the location of the Lyman  $\alpha$  blob immediately between the two MIPS sources suggests a possible physical connection.

#### 4. Ultraviolet-Bright ULIRGs

The detected  $24\mu\text{m}$  flux densities range from 0.2 to 0.6 mJy, which at  $z=2.38$  corresponds to roughly  $4 \times 10^{11}$  to  $10^{12} L_{\odot}$  in rest frame  $7\mu\text{m } \nu F_{\nu}$ . To convert from the mid-infrared to total infrared luminosity, we use the relationship from Chary & Elbaz (2001; ref 2007), calibrated by examining galaxies measured with both ISO and IRAS. Even using conservative mid-infrared conversions puts all the sources in the class of ultra luminous infrared galaxies (ULIRGs;  $> 10^{12} L_{\odot}$ ), or Hyper-LIRGs ( $> 10^{13} L_{\odot}$ ; see Figure 2).

##### 4.1. $\text{Ly}\alpha$ /Mid-IR Relation

A strong correlation between ultraviolet and mid-infrared flux would indicate both emission processes are powered by the same energy source. We can examine this possibility by combining our sample with all the identified blobs with confirmed infrared or submillimeter detections. We plot  $\text{Ly}\alpha$  versus total bolometric luminosity ( $L_{\text{bol}}$ ) in Figure 2.

Applying a similar analysis, Geach et al. (2005; ref 2007) found a weak  $\text{Ly}\alpha$ /Mid-IR relation for their submm-detected  $\text{Ly}\alpha$  blobs with a typical  $L_{\text{Ly}\alpha}/L_{\text{bol}}$

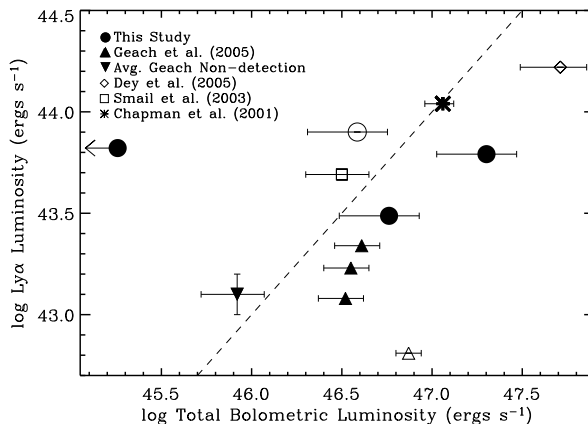


Figure 2. Log Ly $\alpha$  luminosity versus log total bolometric luminosity for high- $z$  Ly $\alpha$  blob ULIRGs. The dashed line marks where the  $L_{\text{Ly}\alpha}/L_{\text{bol}}$  ratio = 0.001. The four blobs from this study are solid squares while the Dey et al. (2005; ref 2007) MIPS source is an asterisk. The sub-mm detections of Ly $\alpha$  blobs are the open triangles ref (2007), circles ref (2007), and diamonds ref (2007). The open square is the non-detected blob average from Geach et al. (2005; ref 2007).

ratio just under 0.1%. Including our  $24\mu\text{m}$ -detected Ly $\alpha$  blobs, which are generally brighter in Ly $\alpha$  than most of the Geach et al. objects, we continue to see the same weak trend, with a  $L_{\text{Ly}\alpha}/L_{\text{bol}}$  efficiency of 0.05-0.2%. While this relation is still tentative, it suggests a direct causal connection between the ULIRG infrared luminosity and the Ly $\alpha$  blobs.

## 5. Nature of the Ly $\alpha$ Blob

### 5.1. Powered by Merger?

The high rate of MIPS detection for the Ly $\alpha$  blobs (75%) demonstrates that these ultraviolet sources are locations of tremendous infrared energy. Two of the Ly $\alpha$  blobs (B6 & B7) seem to be associated with multiple MIPS sources, suggesting a possible interaction or even merger. These separations between possible associated ULIRG component galaxies are large (60-70 kpc) compared to the typical low-redshift ULIRG, which have a median separation around 2 kpc ref (2007). However, interacting ULIRGs with wide separations on the scale of 50 kpc do exist ref (2007), and seem to occur when at least one the interacting galaxies is highly gas-rich ?.

Previous high resolution *HST* imaging also indicates a possible Ly $\alpha$  blob connection to merging galaxies. For instance, NICMOS imaging of blob B1 shows a pair of compact, red galaxies with a projected separation of less than 7 kpc ref (2007). Only three other Ly $\alpha$  blobs have been imaged with *HST*: the blobs in the field of 53W002, one of which shows a second nearby galaxy ref (2007), and blob SSA22a-C11 which STIS imaging shows to be composed of several likely interacting components ref (2007).

In the local universe, the most energetic mergers are associated with the ULIRGs, with roughly 90% of all ULIRGs clearly interacting ref (2007). The majority of local ULIRG mergers are between two low mass ( $0.3-0.5 L^*$ ) galaxies ref (2007), but major mergers of high-mass galaxies, like those predicted to build giant ellipticals, must be occurring at higher redshift. If merger-induced star formation is the source of the majority of the infrared flux in these objects, it implies star formation rates of 1000s of  $M_\odot \text{ yr}^{-1}$ , like those suggested for some sub-mm sources ref (2007). Such massive SFRs would be capable of generating the supernova kinetic energy needed to drive a superwind and power the  $\text{Ly}\alpha$  blobs. If supernovas deposit roughly  $10^{49}$  ergs per solar mass of stars into the surrounding medium ref (2007), a star formation rate of  $1000 M_\odot \text{ yr}^{-1}$  will easily match the  $\sim 10^{51}$  ergs  $\text{yr}^{-1}$  emitted by the blobs, even at a low efficiency.

Mergers could also help drive gas inwards into a supermassive black hole, making AGN another viable infrared energy source, with escaping ultraviolet radiation driving the  $\text{Ly}\alpha$  blobs. Previous HST WFPC2 imaging of nine moderate redshift ( $z=0.45-1.33$ ) Hyper-LIRGs showed only three interacting systems compared to six point-like QSOs ref (2007), showing that at low to moderate redshifts, higher energy sources appear to be AGN-powered. Eight of those nine Hyper-LIRG systems also showed some sort of nearby companion.

Cooling flows also remain a possibility, as it might be common to find multiple galaxies merging at the center of such a large inward flow of gas. It does become a less favored model, however, as the energy from the cooling gas is no longer required to power the  $\text{Ly}\alpha$  blobs. The ULIRGs would appear to have more than enough energy in their budget to do so on their own.

## 5.2. Optical through IRAC SEDs

We can gain further information on the origin of the energy for these sources by examining the optical through infrared SEDs, particularly the IRAC bands (Figure 3). We detect 3 of the 4  $\text{Ly}\alpha$  blobs in the near-infrared and all four of the  $\text{Ly}\alpha$  blobs in all the IRAC bands. The three near-IR detected blobs show a clear  $4000\text{\AA}$  break at the expected location for a source at a redshift of  $z=2.38$ .

A galaxy whose energy output is dominated by star formation is predicted to have a strong  $1.6\mu\text{m}$  bump ref (2007), which would be located in channel 3 ( $\sim 5.5\mu\text{m}$ ) at this redshift. None of the  $\text{Ly}\alpha$  blobs show this clear  $1.6\mu\text{m}$  bump. However, neither is there a steep rise from channels 3 to 4, which would be a clear indication of domination by an AGN. It is therefore likely these  $\text{Ly}\alpha$  blobs are composite sources, containing at least moderate amounts of both star formation and AGN activity. Although an AGN can make up a significant percentage of the total flux at  $2-5\mu\text{m}$ , where they dominate the hot dust, they do not necessarily contribute more than a tiny amount to the total bolometric luminosity ref (2007). Therefore longer wavelength observations will be required to properly identify the primary source of the  $\text{Ly}\alpha$  blob's energy.

We note that the IRAC spectrum of B5 is not consistent with that of a  $z=2.38$  galaxy, despite the strong break at the proper location of  $4000\text{\AA}$ . Other evidence also suggests this may be a chance superposition of two sources, strongly complicating further analysis.

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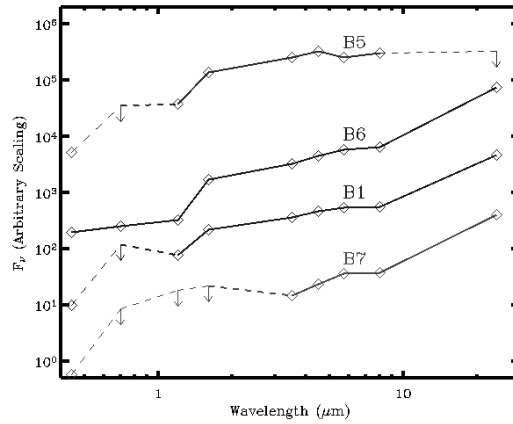


Figure 3.  $F_\nu$  versus wavelength for our four Ly $\alpha$  blobs. Diamonds mark detections while arrows designate upper limits. The  $F_\nu$  scaling is arbitrary.

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